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RESEARCH MEMORANDUM

PERFORMANCE OF MULTIPLE JET-EXIT INSTALLATIONS

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SUMMARY

This paper presents the results of recent exploratory investigations of the performance of clustered jet-exit installations at Mach numbers from 0.60 to 3.05. Data presented herein were obtained with tunnel-wall-mounted models with cold-air-jet exhaust. The results indicate that large base-pressure drag coefficients may be encountered in the transonic and low supersonic speed range and that the best configuration investigated was boattailed between the nacelles, had a cylindrical nacelle afterbody, and a divergent nozzle with a design pressure ratio of 15. It was also indicated that afterbody terminal fairings or base bleed might be used to reduce the performance losses of overexpanded nozzles. If the terminal fairings or base bleed were applied to fixed ejector geometry, an important saving in weight and complexity would result.

INTRODUCTION

Recent supersonic airplane designs, where the engines are clustered along the trailing edge of the wing in a side-by-side arrangement, have raised many questions relative to internacelle and interjet interferences on the base and afterbody drag. The purpose of this paper is to discuss the results of some recent investigations of clustered exit installations. Tests were conducted at Mach numbers from 0.60 to 3.05 with jet total-pressure ratios up to 40.

SYMBOLS

C_D drag coefficient, $\dfrac{D}{qS}$

$C_{D,b}$ base-pressure drag coefficient

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*Title, Unclassified.

C_F $\qquad$ thrust coefficient, $\dfrac{F}{qS}$

$C_{p,b}$ $\qquad$ base pressure coefficient, $\dfrac{p_b - p_\infty}{q}$

D $\qquad$ drag

F $\qquad$ thrust

M $\qquad$ Mach number

p_b $\qquad$ base pressure

$\dfrac{p_{t,j}}{p_\infty}$ $\qquad$ ratio of jet total pressure to free-stream static pressure

p_∞ $\qquad$ free-stream static pressure

q $\qquad$ dynamic pressure

S $\qquad$ assumed model wing area, 0.37 sq ft

$\Delta\left(C_F - C_D\right)$ $\qquad$ incremental thrust-minus-drag coefficient

θ $\qquad$ nozzle divergence angle

β $\qquad$ boattail angle

APPARATUS

An exploratory investigation has been conducted in the Langley
9- by 12-inch blowdown tunnel and in the Langley internal aerodynamics
laboratory by using wall-mounted models which approximately duplicated half
of the configuration shown in figure 1. Interchangeable exit configurations
with different amounts of boattailing, nozzle-divergence angles, and
afterbody terminal fairings are presented subsequently. The jet exhaust
was simulated with cold air; numerous test data have shown that this
simulation is adequate for an exploratory investigation of this type.
(See refs. 1 and 2.) Base pressures, surface pressures between the
nacelles, drag, and thrust-minus-drag were measured, and flow-visualization
studies have been made over the Mach number range.

RESULTS AND DISCUSSION

Base Pressures

Effect of pressure ratio at transonic speeds.- Figure 2 shows the base-pressure coefficients of side-by-side arrangements at transonic speeds. The average base-pressure coefficient obtained by averaging the pressures over the base is plotted against the ratio of jet total pressure to free-stream static pressure at Mach numbers of 0.90 and 1.25. Data are for a three-engine configuration with a jet-to-base diameter ratio of 0.5 and sonic exits. This configuration is a basic model with slight boattailing and a flat base and is not intended as a practical configuration; however, configurations with similar lines have been proposed where large amounts of secondary flow are available for base bleed. Single-engine nacelle data are shown for comparison, inasmuch as wide ranges of shape variables have been investigated on single-engine nacelles at transonic and supersonic speeds. The data for the single-engine configuration are for a cylindrical nacelle with a sonic jet exit and the same base-to-diameter ratio as the three-engine clustered configuration. The data indicate that the trends of the single-engine and the three-engine configurations are very similar; thus, the single-engine nacelle data could probably be applied qualitatively to the clustered exit design. The important thing in figure 2, however, is the magnitude of the base-pressure coefficient, inasmuch as the peak negative values occur near the operating pressure ratios for supersonic engines for each Mach number. In fact, at a Mach number of 1.25 for a six-engine airplane with 5-foot-diameter nacelles and 6,000 square feet of wing area, the base-pressure drag coefficient would be 0.0066. This value of $C_{D,b}$ indicates that, in a region where the thrust margin of the supersonic engine may be a minimum, the base-pressure drag may be a maximum; consequently, there would be an increase in acceleration time and a loss in airplane range.

Effect of Mach number.- Figure 3 shows the effect of Mach number on base-pressure coefficient. The average base-pressure coefficient is plotted against Mach number at pressure ratios corresponding to the schedule of engine-pressure-ratio variation with Mach number shown in this figure. This pressure-ratio schedule is considered to be typical for the supersonic engine. The data shown in the transonic speed range are for the three-engine configuration shown in figure 2 with sonic jet exits. The data shown at Mach numbers of 1.62 and above are for a similar flat-base configuration with convergent-divergent nozzles with design pressure ratios of 8. The nozzles are underexpanded for all Mach numbers above 1.62; however, this is the design condition for some supersonic engine configurations. Expansion ratios greater than this value would make $C_{p,b}$ more negative. The data indicate

that the base-pressure coefficient reaches a peak negative value between Mach numbers of 1 and 1.5 and then falls rapidly with an increase in Mach number. The value looks small at a Mach number of 3.05; however, if it were applied to the six-engine airplane with a wing area of 6,000 square feet mentioned previously, the base-pressure drag coefficient would be about 0.0010 or approximately 7 percent of the expected total drag of such a configuration.

Effect of Boattailing

The question arises - how much should the clustered exit configuration be boattailed? Shown in figure 4 are three configurations with various amounts of boattailing. All three of these configurations have the same internal nozzle contour, namely, convergent-divergent nozzles with design pressure ratios of about 8. Configuration 1 is an idealized configuration with zero base area and 6° of boattailing on the individual nacelle. It is also boattailed between the individual nacelles. Configuration 2 has cylindrical nacelles, a base annulus, and boattailing between the nacelles. Configuration 3 has no boattailing whatsoever. As was stated previously, consideration has been given to configurations with flat bases similar to configuration 3.

Figure 5 shows the effect of boattailing on incremental thrust minus drag coefficient. The incremental thrust minus drag is obtained by subtracting the measured thrust minus drag of the configuration from that of configuration 1 at pressure ratios corresponding to the schedule with Mach number also shown in the figure. Configuration 1 will be used as the reference configuration in all subsequent plots of $\Delta\left(C_F - C_D\right)$ in this paper. The data indicate that progressive boattailing from configuration 3 to configuration 1 results in a reduction of drag in that same order. It appears that the overall boattailing of the configuration may be more important than that of the individual nacelle, since configuration 2 has reduced the drag so that it approaches that of configuration 1. Base pressures measured on configurations 2 and 3 at a Mach number of 3.05 indicate that the jet interference due to the underexpanded jet has a more marked beneficial effect on configuration 2 than on configuration 3, as is shown in figure 6. The improvement to configuration 3 that would be obtained by the addition of base bleed is unknown, but it is expected that base bleed would provide a small improvement in base-pressure drag coefficient.

Effect of Afterbody-Nozzle Geometry

In figure 5 the effect of boattailing with fixed nozzle geometry was shown. Figure 7 shows three configurations which represent a schedule

of afterbody-nozzle geometry over the Mach number range where each setting is designed to produce optimum thrust at a particular Mach number. Configuration 1 is repeated from the previous figures and configuration 4 represents a maximum afterburner setting with a cylindrical nacelle and a convergent-divergent nozzle with a design pressure ratio of 15 at a Mach number of 2.4. Configuration 5 represents an intermediate setting with a design pressure ratio of 11 and design flight Mach number of 1.9.

The variation of incremental thrust-minus-drag coefficient with Mach number for these three configurations is shown in figure 8. The data are presented for the pressure-ratio schedule also shown in figure 8. It is indicated that configuration 4 is better than the other two configurations over the entire Mach number range. It would be expected that configuration 4 would be the best above a Mach number of 2.4, since it has a zero pressure drag nacelle and the nozzle is at or above its design pressure ratio. In other words, it is developing more divergent nozzle thrust above this Mach number. The low value of $\Delta\left(C_F - C_D\right)$ of configuration 4 suggests the possibility of even better performance near $M = 3.0$ with a larger nacelle and a nozzle having a higher design pressure ratio. It is surprising that configuration 4 does not exhibit more of the expected large overexpansion losses at speeds below design. It is noted that some delay in experiencing these losses has already occurred, probably because of external stream and separation effects in the nozzle. It may also be caused by the low Reynolds number of the internal flow. If the good performance of configuration 4 can be maintained into the transonic speed range by eliminating the overexpansion losses which are known to occur (see ref. 3), it might be possible to operate the clustered exit over the Mach number range of this investigation with fixed ejector geometry and thereby make a large saving in weight and complexity.

Terminal Fairings

Figure 9 shows photographs of two special devices which were investigated at transonic speeds in an attempt to reduce the overexpansion losses of fixed ejector geometry and to improve the configuration performance. To the first device, shown in the upper left of the figure, six bodies have been applied to a combination of a low-design-pressure-ratio convergent-divergent nozzle and a curved-afterbody, and these fairings are very carefully designed to increase the effective fineness ratio of the afterbody and to provide surfaces for the underexpanded jet to act upon. The slotted afterbody shown in the lower right of the figure is a variation of the terminal fairing idea which looks a little more conventional. It consists of a basic curved afterbody with a fixed-divergent ejector designed for a pressure ratio of 10 with longitudinal slots cut into the ejector throat to ventilate the surface at sonic

speeds. Both of these terminal fairing models showed significant improvement in thrust minus drag over their basic configurations throughout most of the transonic speed range.

Since some success had been attained at transonic speeds, terminal fairings were applied to the flat-base configuration (configuration 3), and figure 10 shows the complete model used for the supersonic investigation with the terminal fairings installed. The internal contour of the nozzles is the same as that of the flat-base configuration and the boattailed configuration (configuration 1) that was shown earlier. The results shown in figure 11, where $\Delta(C_F - C_D)$ is plotted against Mach number for the pressure-ratio schedule shown in the figure, indicate that the fairings provide a significant improvement over the flat-base configuration. In fact, they reduce the drag about one-half the way toward configuration 4, which was the best studied. The drag of the fairing model was about the same as the best of the boattail series shown here as the reference. Obviously, the fairings could have been applied to a boattailed design and, of course, the fairing design has not been optimumized in the supersonic speed range. The success gained to date with these terminal fairings indicates the need for further research on this type of design.

CONCLUSIONS

Recent exploratory investigations of the performance of clustered jet-exit installations at Mach numbers from 0.60 to 3.05 indicated the following conclusions:

1. There is a large amount of single-engine data available that would apply qualitatively to the clustered-exit design.

2. The clustered-exit installations may encounter very large base pressure drags in the transonic and low supersonic speed range where the exit nozzle is closed down to provide maximum internal performance.

3. Significant effects of configuration geometry were shown with the indication, at least, that overall boattailing may be more powerful than that of the individual nacelle.

4. The best configuration investigated was a cylindrical nacelle with boattailing between the nacelles and a convergent-divergent exhaust nozzle with a design pressure ratio of 15. This configuration was superior well into the region where the nozzle was overexpanded. It appears that, if some method of delaying these adverse overexpansion effects can be found, important savings in weight and complexity can be

gained by fixed ejector geometry. One possible method of accomplishing this is by the use of terminal fairings and another method may be by the use of base bleed.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., March 20, 1958.

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2. Baughman, L. Eugene, and Kochendorfer, Fred D.: Jet Effects on Base Pressures of Conical Afterbodies at Mach 1.91 and 3.12. NACA RM E57E06, 1957.

3. Swihart, John M., and Mercer, Charles E.: Investigation at Transonic Speeds of a Fixed Divergent Ejector Installed in a Single-Engine Fighter Model. NACA RM L57L10a, 1958.

CLUSTERED ENGINE ARRANGEMENT
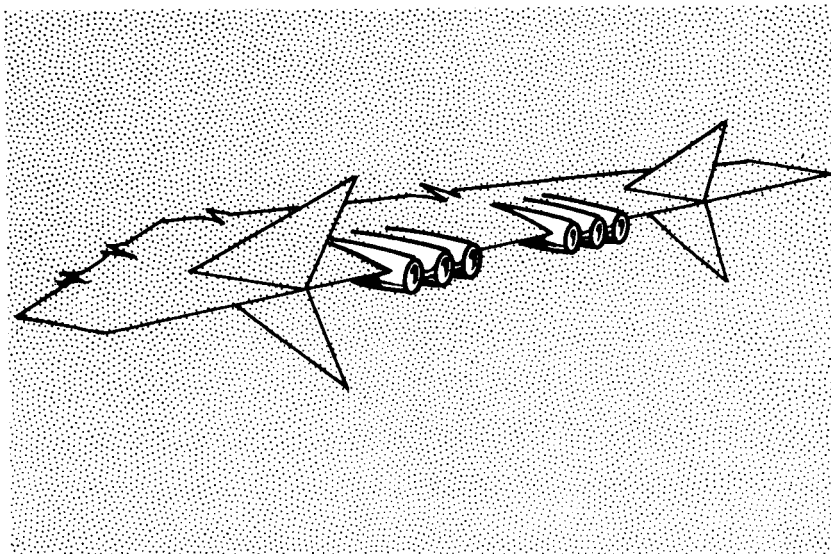
Figure 1

TRANSONIC BASE PRESSURE
JET EFFECT OF SIDE-BY-SIDE NACELLES
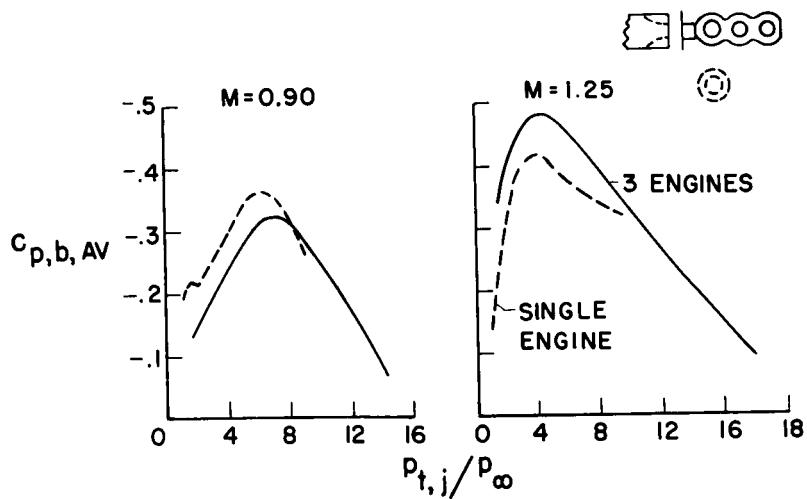
Figure 2

EFFECT OF MACH NUMBER ON BASE PRESSURE COEFFICIENT

$c_{p,b,AV}$

$\frac{p_{t,j}}{p_\infty}$
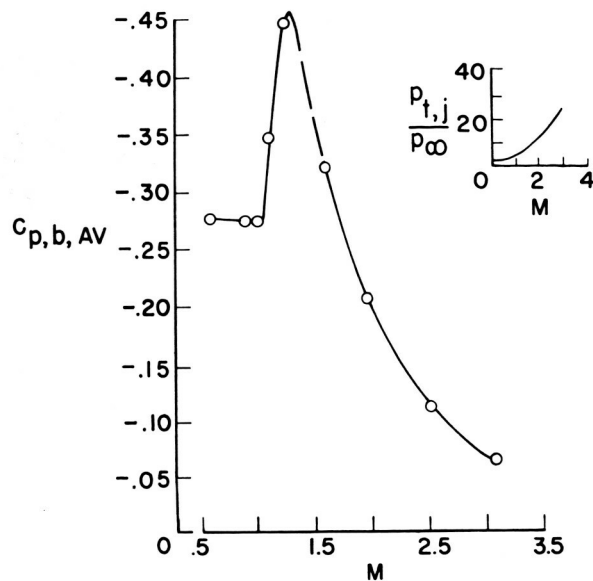
Figure 3
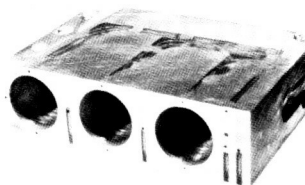
AFTERBODY GEOMETRY
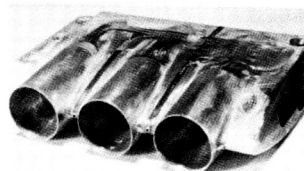
CONFIGURATION 1
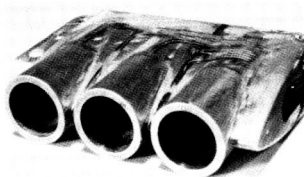
CONFIGURATION 2

CONFIGURATION 3

L-58-122
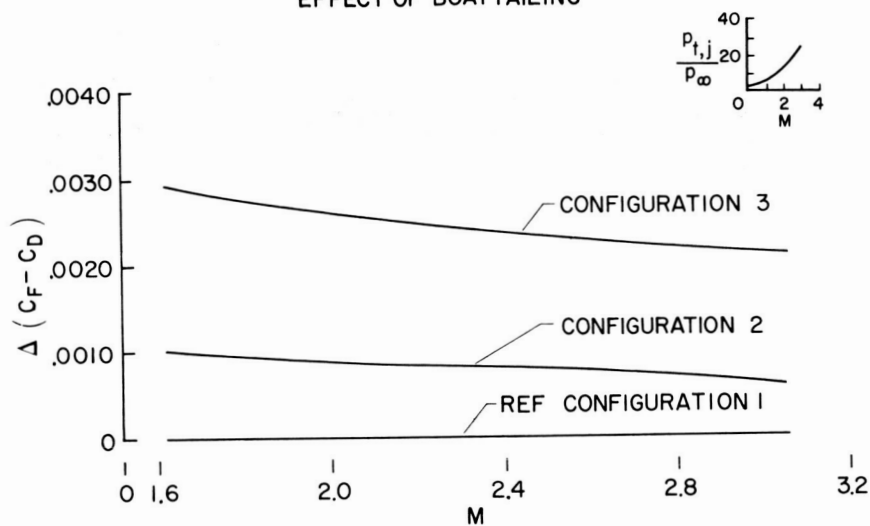
Figure 4

INCREMENTAL THRUST-DRAG
EFFECT OF BOATTAILING
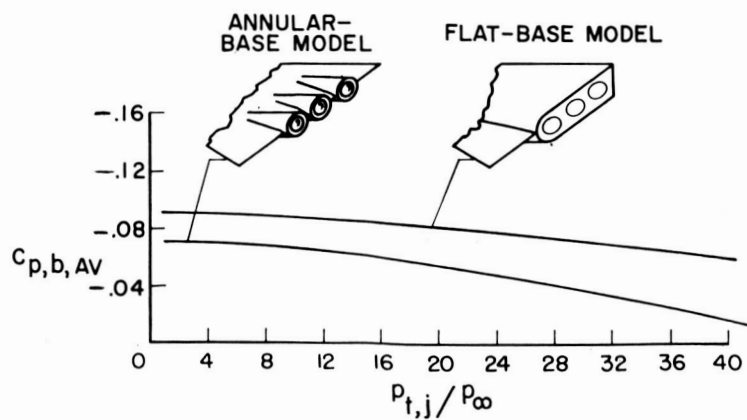

Figure 5

BASE PRESSURE COEFFICIENTS
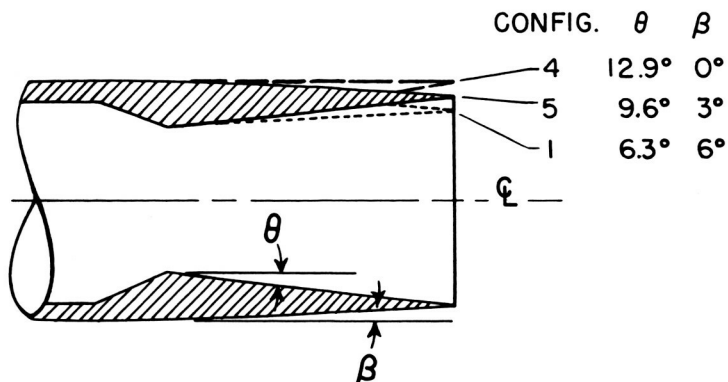M = 3.05

Figure 6

BOATTAIL AND NOZZLE GEOMETRY

CONFIG.	θ	β
4	12.9°	0°
5	9.6°	3°
1	6.3°	6°

Figure 7

INCREMENTAL THRUST-DRAG
BOATTAIL AND NOZZLE VARIED SIMULTANEOUSLY

REF CONFIGURATION I

CONFIGURATION 5
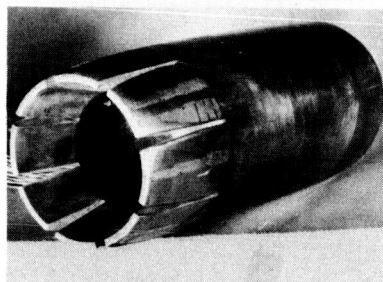
CONFIGURATION 4

$\Delta(c_F - c_D)$

$\frac{p_{t,j}}{p_\infty}$

M
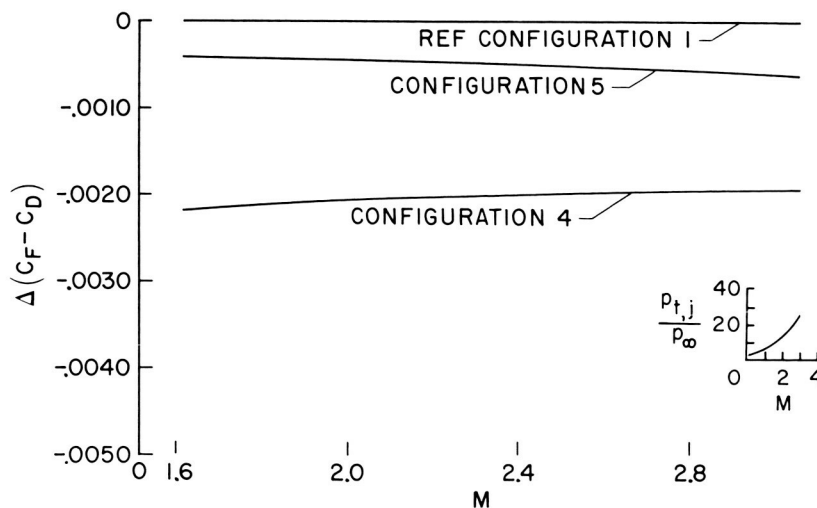
Figure 8

TERMINAL FAIRINGS
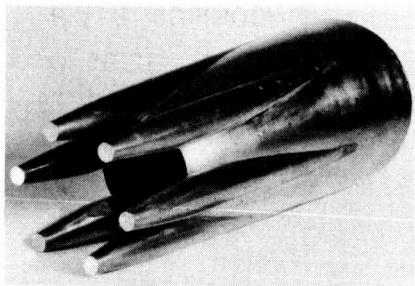
SIX FAIRINGS

SLOTTED AFTERBODY

L-58-856

Figure 9

TERMINAL FAIRINGS APPLIED TO CLUSTERED EXIT ARRANGEMENT

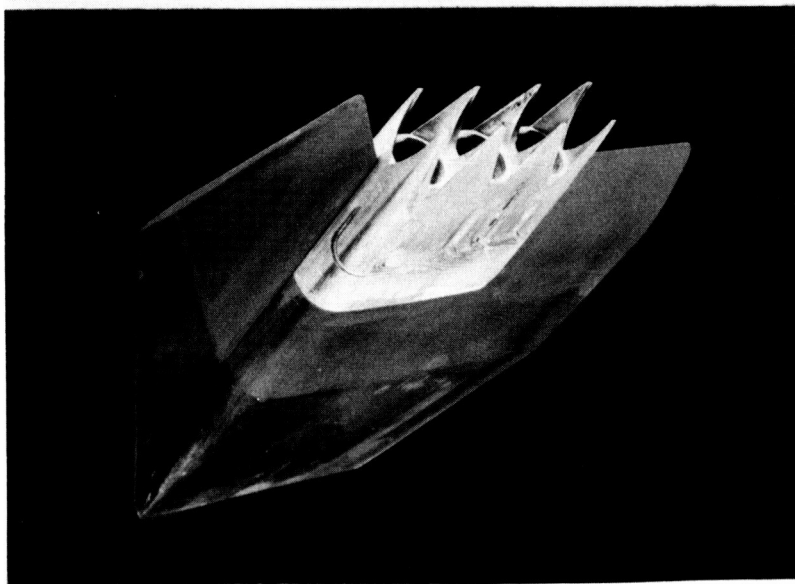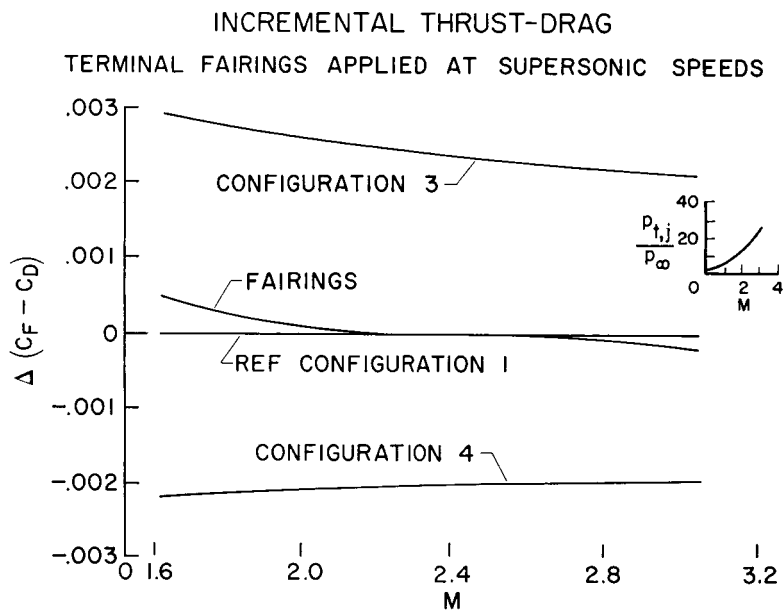L-58-27

Figure 10

INCREMENTAL THRUST-DRAG

TERMINAL FAIRINGS APPLIED AT SUPERSONIC SPEEDS

Figure 11